REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-00-

0219

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		01 Aug 96 to 31 Jul 99 Final

4. TITLE AND SUBTITLE
(DURIP96) Development of an ultrafast scanning tunneling microscope for dynamic surface studies

5. FUNDING NUMBERS
61103D
3484/US

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NE
801 North Randolph Street Rm 732
Arlington, VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
F49620-96-1-0396

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVAL FOR PUBLIC RELEASED; DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

At the end of three years, we have met the majority of the project goals and made significant progress on the few remaining issues. As outlined in more detail below, we have designed and built a UHV system and incorporated a commercially made, custom designed STM. The microscope has demonstrated atomic resolution. We have a femtosecond laser system, optics for delivering ultrafast laser pulses to the STM, and a computer controlled delay line for time-resolved measurements.
This project also has funding from the National Science Foundation, and work continues with that funding while we actively seek additional funds for continued work. We are actively working to develop the instrument as a probe-station for molecular electronics. To that end, we are collaborating with Prof. David Glueck in the Chemistry department on time-domain investigations of Coulomb-blockade effects in Au nanoparticles.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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96-1-0396

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FINAL PERFORMANCE REPORT

DEVELOPMENT OF AN ULTRAFAST SCANNING TUNNELING MICROSCOPE FOR DYNAMIC SURFACE STUDIES

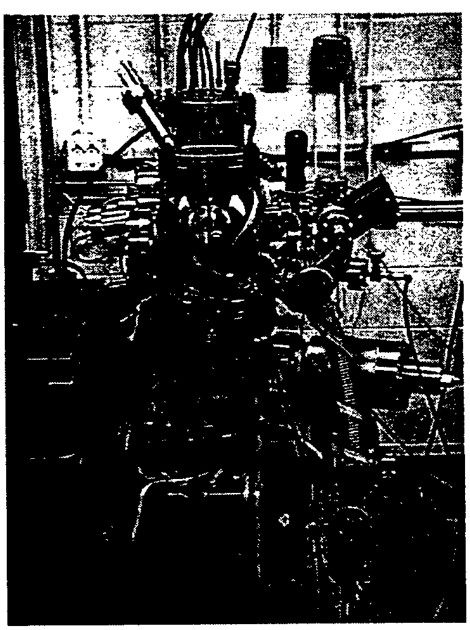
AFOSR-DURIP

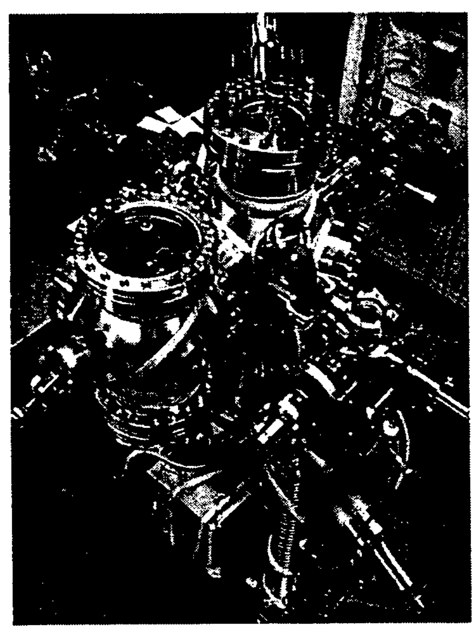
At the end of three years, we have met the majority of the project goals and made significant progress on the few remaining issues. As outlined in more detail below, we have designed and built a UHV system and incorporated a commercially made, custom designed STM. The microscope has demonstrated atomic resolution. We have a femtosecond laser system, optics for delivering ultrafast laser pulses to the STM, and a computer controlled delay line for time-resolved measurements.

The main obstacles to progress have been the strong U.S. economy which has made the hiring and retention of postdoctoral staff extremely difficult. The long delays associated with hiring these staff members were compounded by the University of Alberta's failure to live up to it's agreement to provide us with semiconductor photoswitches. At present, however, we have a postdoctoral staff member with a strong backround in semiconductor processing and device design, and we are on track to develop these switches on our own.

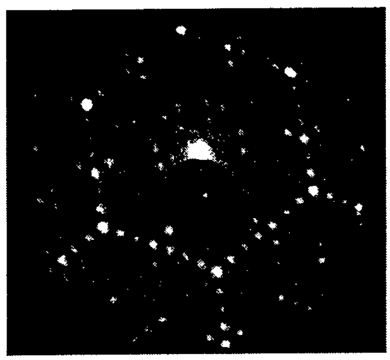
1. UHV chamber and diagnostic system.

The ultra-high vacuum chamber for this system includes ion, Ti sublimation, and turbo pumping systems. Base pressures on the order of 5×10^{-11} Torr are routinely obtained. The system includes a load-lock and magnetically driven transfer arm for the introduction of samples without breaking vacuum in the main chamber. For chamber diagnostics, we have included a residual gas analyzer (up to 100 amu). The chamber, with the scanning tunneling microscope in the foreground, is pictured in the figures below. The entire system is mounted on a vibration isolated optical table.



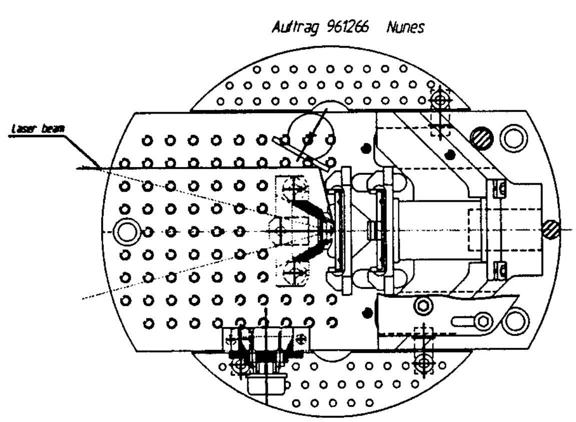


The sample manipulator allows indirect heating of samples up to 900 C, and direct (ohmic) heating of semiconductor samples. A controlled low dosage electron beam evaporator allows the deposition of thin films with sub-monolayer control. In-situ surface cleaning can be accomplished with a differentially pumped ion-beam system. Sample preparation diagnostic tools include a deposition thickness monitor and a low energy electron diffraction (LEED) system. The LEED instrument has the capability of providing Auger spectra, but has so far only been used as an imaging tool. It has already proven to be a key tool in resolving a materials issue that was preventing us from achieving atomic resolution with the tunneling microscope. A sample diffraction pattern from a silicon crystal is shown below.

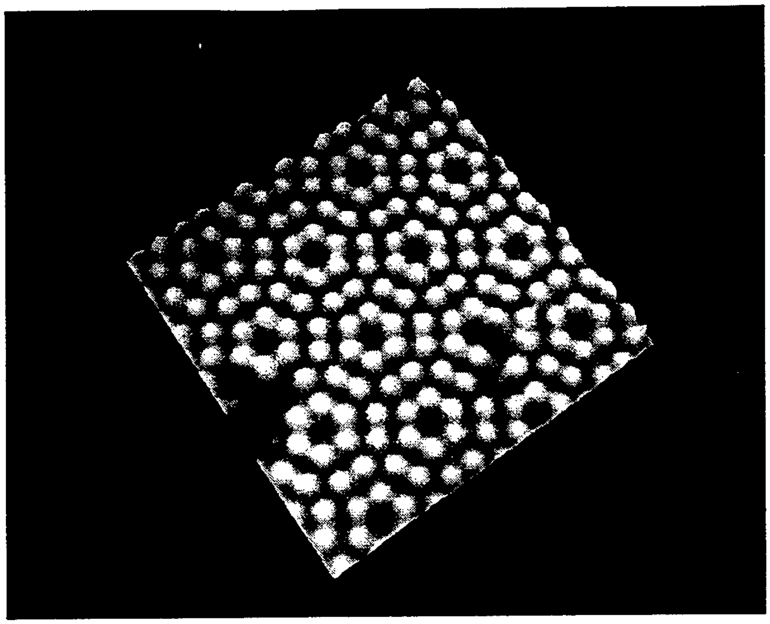


2. STM

The scanning tunneling microscope was custom designed and built to our specifications by Omicron Instruments. Key features include an in-vacuum vibration isolation stage, vacuum interchange of both sample and tips, and a full control system including spectroscopy and electronic drift compensation. The design of the instrument includes a miniature optical table on the STM platform and optical access from above and from behind the STM tip. A schematic of the STM platform is shown below illustrating the optical table, tip, sample holder/scanner, in-vacuum preamplifier, and electrical patch panels.

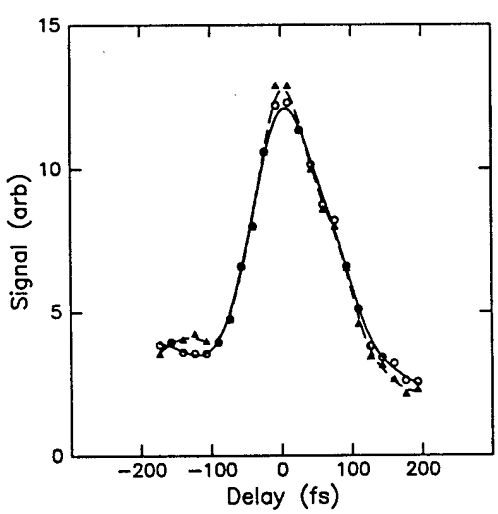


As delivered, the instrument met our specification of atomic resolution. A sample image of the Si (111) surface is shown below.



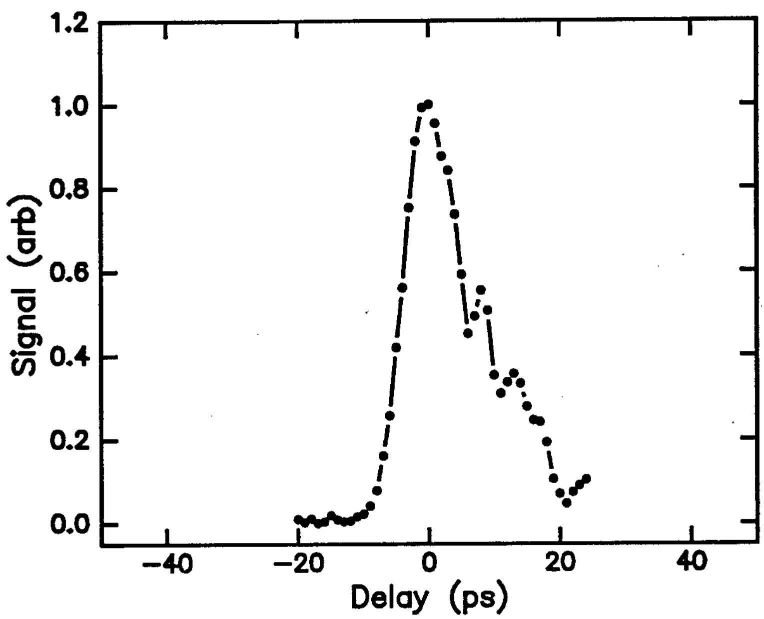
3. Laser system and optics

For sample and photoswitch excitation, we purchased an all solid-state titanium-sapphire laser system from Coherent. The system has extremely low noise, is highly reliable, and offers essentially turn-key operation. Routine monitoring of the laser pulse width is provided by an auto-correlator system. For data acquisition we developed a computer controlled delay line with 15 fsec resolution. The figure below shows a cross-correlation of the laser pulse obtained using this system. Two separate scans are shown to indicate the system reproducibility.



4. Photo switches

The aspect of this project that has proven the most vexing is the design and implementation of photoswitches for the time-resolved tunneling. As outlined in our proposal, we had a collaborative arrangement with the University of Alberta under which they would provide us with photoswitches. For a variety of reasons they have been unable to honor that agreement. Therefore, we have been forced to undertake this project ourselves. The result has been painfully slow going, and has involved a lot of "learning under fire." Up to now, our best performing switches have a time-response as illustrated below. We now believe, however, that we have a handle on the important design issues involved in designing fast switches, and also an understanding of the important materials issues. We currently have an agreement to obtain small quantities of low-temperature grown GaAs from Eicke Weber's group at UC Berkeley. We should receive our fist sample of this material in May of 2000.



5. Future Work

This project also has funding from the National Science Foundation, and work continues with that funding while we actively seek additional funds for continued work. We are actively working to develop the instrument as a probe-station for molecular electronics. To that end, we are collaborating with Prof. David Glueck in the Chemistry department on time-domain investigations of Coulomb-blockade effects in Au nanoparticles.